is of brass divided to degrees. "Newman (Makerstoun)" is the instrument which was supplied to the Makerstoun Observatory as a standard, and to whose indications the results of the temperature observations made there since 1841 have been "corrected." It was, at my suggestion, sent to Kew by Sir Thomas Brisbane for comparison with our standards. "Troughton and Simms (Royal Society)" is a standard belonging to the Royal Society. As its scale extends to above 212, its boiling-point was examined in the same apparatus employed for the Kew standards, its brass scale remaining attached to the tube. It was found to read 212°·7 when the barometer, reduced to 32°, stood at 30·136 inches.

The errors of a thermometer which has been already carefully examined between 32° and about 100°, may be obtained with considerable accuracy for temperatures below 32°, without using a freezing mixture, by the following process. Detach from the column of mercury a portion which will occupy about 40 or 50 degrees of the scale: bring this column within the known part of the scale. Let a, b be the readings at the upper and lower ends respectively; α, β the index errors at these points as determined by comparison with a standard. Move the column until its lower end coincides with some degree below 32°, the upper end being within the compared portion of the scale. Let c, d be the scale-readings for the upper and lower ends in the new position, γ being the scale error corresponding to c. The error of the scale at d will then be

$$d-\{\overline{c-\gamma}-(\overline{a-\alpha}-\overline{b-\beta})\}.$$

The true length of the detached column may be obtained with increased accuracy by taking a mean of several measures within the known part of the scale. This method was adopted for "Newman (Makerstoun)" and "Troughton and Simms (Royal Society)," and the following errors obtained:—

Newman (Makerstoun). Temperature.	Error.	Troughton and Simms (R.S.). Temperature.	Error.
0°·7	−0°·05	5°·1	+0°·14
6·2	−0·08	10·0	+0·17
10·7	−0·12	15·0	+0·16
14·6	−0·10	20·0	+0·16
20·2	−0·04	24·8	+0·16
25·8	0·00		

The error of "Newman" had been previously found, by comparing with a standard in a freezing mixture at −3°, to be inappreciable.

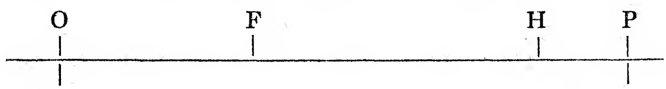
Mr. Welsh's Report, No. 2.

"On the Graduation of the Thermometers supplied from the Kew Observatory for the use of the Arctic Searching Expedition under Sir Edward Belcher."

These instruments were twelve in number, seven mercurial and five spirit thermometers, graduated for low temperatures. The pro-

cesses adopted for the two kinds of instruments being different, I shall describe them separately.

I. *Mercurial Thermometers.*—These were divided into degrees of Fahrenheit's scale in the following manner:—The tube was first calibrated in the way already described in my former report on the construction of thermometers (dated March 22); marks being made on the tube at each extremity of the calibrated space. The bulb was then made and the mercury introduced by the glass-blower, the dimensions of the bulb and the quantity of fluid being made as nearly as possible to correspond with the scale proposed to be made. The thermometer was then placed in melting ice and the freezing-point approximately set off with an ink mark; a similar mark being also made for a temperature of between 95° and 100°. A short arbitrary scale of four or five divisions was then divided at each of those points. The thermometer was then again placed in ice and the freezing-point determined accurately with reference to the lower short scale; and comparisons with two standard thermometers in water determined the value of the upper short scale. Let OP be the calibrated portion of the tube, O being the point of commencement, F the



freezing-point as determined by means of the short arbitrary scale, and H the higher point of the scale similarly obtained. Let the distances OF, FH, HP be measured by the screw of the dividing engine. Let R_1, R_2, R_3, &c., R_f, &c., R_h, &c. be the lengths, in revolutions of the dividing screw, of the calibrating column of mercury for each successive step in its progress along the tube during the process of calibration; R_f being the length of the step in which the point F occurs, and R_h that in which H occurs. The values of R_1, R_2, &c. have been registered in the process of calibration; OF and OH have been obtained independently; the second measurement of OP, when compared with the sum of all the R's, will show with what exactness* the column of mercury has been passed through its own length in its progress along the tube. Let r_f be the number of revolutions between the first end of the step f and the point F, and similarly r_h for the step h. We have then

$$\mathrm{OF} = R_1 + R_2 + R_3 + \&c. + R_{f-1} + r_f$$

$$\text{and } \mathrm{OH} = R_1 + R_2 + \; . \; . \; . \; . + R_{h-1} + r_h;$$

whence we obtain r and r_h. Let K be the number of degrees equivalent to one length of the calibrating column,—this being of course constant for each length along the tube on the supposition of equal increments of volume for equal increments of temperature.

* If this should be found slightly in error, it can produce no appreciable error in the graduation, as an error could only arise from the alteration of the tube's capacity, which might take place in a length equal to the difference found, this difference being in perhaps no case more than $\frac{1}{100}$ or $\frac{1}{50}$ inch.

Also, if we suppose that the capacity of the tube does not vary throughout the length of a single calibrating step, $\frac{r_f}{R_f}$ and $\frac{r_h}{R}$ will give the fractional parts of a step by which the points F and H are respectively in advance of the first ends of the steps f and h. We have then

$$OF=\left(\overline{f-1}+\frac{r_f}{R_f}\right)K, \quad OH=\left(\overline{h-1}+\frac{r_h}{R_h}\right)K;$$

and $FH=\left(h-f+\frac{r_h}{R_h}-\frac{r_f}{R_f}\right)K=T_h$, the higher temperature$-32°$;

whence $K=\dfrac{T_h}{h-f+\frac{r_h}{R_h}-\frac{r_f}{R_f}}$. The degree corresponding to the point O is $32°-\left(\overline{f-1}+\frac{r_f}{R_f}\right)K$. The length of one degree for any individual step x is $\frac{R_x}{K}$.

From the quantities thus obtained, a table may readily be formed showing the value in revolutions of the dividing screw of one degree at all parts of the scale, and the graduation may then be proceeded with accordingly. The graduation is carried from $-40°$ to $+120°$ or $130°$ Fahr.

II. *Spirit Thermometers*.—In the graduation of mercurial thermometers, the practice is to consider the increments of volume to be proportional to increments of temperature. If this were assumed in the case of spirit thermometers, very serious errors would be the result, even within moderate ranges of temperature. Dr. Miller having considered alcohol, as on the whole, the best fluid for thermometers intended to measure very low temperatures, I was supplied by him with some which he had himself prepared with great care, its specific gravity being 0·796 at 60° Fahr. The first step to be taken was the determination of the *law* of expansion of the fluid in glass, as compared with that of mercury. For this purpose a tube was calibrated and divided with an arbitrary scale according to Regnault's process: its divisions were found, upon verification, to be of exactly equal capacity throughout. The tube was then furnished with a bulb of the same dimensions as those intended to be supplied to the Admiralty, and filled with the alcohol. This thermometer was marked S. 9 E. Comparisons were then made between the readings of this instrument and those of a standard mercurial thermometer, through as large a range of temperature as was found practicable. The comparisons above the freezing-point were taken in water, in the apparatus described in my former report; those below 32° were taken in freezing mixtures of ice and salt or chloride of calcium. The following Table contains the results of two series

of experiments; the numbers in the first two columns are differences from the freezing-point; those in the first being Fahrenheit's degrees; and in the second and third columns, the arbitrary scale divisions of the spirit thermometer S. 9 E.

Table, containing results of comparisons between a Standard Mercurial Thermometer, and a Spirit Thermometer with an arbitrary scale of uniform capacity.

First Series.			Second Series.		
Standard mercurial thermometer.	Spirit thermometer S. 9 E.	S. 9 E. Observed *minus* calculated.	Standard mercurial thermometer.	Spirit thermometer S. 9 E.	S. 9 E. Observed *minus* calculated.
°	Scale div.	Scale div.	°	Scale div.	Scale div.
+69·95	+209·5	+0·2	+65·76	+196·4	+0·2
+66·93	+199·7	−0·1	+60·04	+178·3	0·0
+53·15	+156·7	−0·3	+52·04	+153·5	−0·1
+40·53	+118·2	−0·3	+37·72	+110·3	+0·2
+20·83	+ 60·1	+0·2	+24·05	+ 69·8	+0·4
+17·80	+ 51·0	−0·1	+16·01	+ 46·7	+0·8
−18·44	− 50·5	+0·9	−16·38	− 44·8	+0·9
−36·15	− 98·0	+1·2	−29·00	− 79·7	+0·4
−43·14	−117·9	−0·2	−36·33	−100·2	−0·5
			−44·72	−123·0	−1·1

To deduce the law of expansion from these comparisons, the numbers were arranged in equations of the form

$$AT+BT^2-N=0, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1.)$$

where T is the number of Fahrenheit's degrees from 32°, N the corresponding number of divisions by thermometer S. 9 E., A and B being the constants whose value is to be ascertained: the constants depending on higher powers of T than the second, were not considered.

The values of A and B were obtained from the equations by the method of least squares, and were as follows:—

From first series .... A=2·8203 ...... B=0·002455
From second series .... A=2·8377 ...... B=0·002221
The mean of both series giving .. A=2·829 ...... B=0·002338

The numbers in the columns "Observed *minus* calculated," are obtained by taking the difference between the observed readings of the spirit thermometer, and the numbers calculated from the *mean* values of A and B just stated.

Having determined upon the adoption of the law of expansion stated above, the graduation of the spirit thermometer was proceeded with as follows.

The process of calibrating the tubes was the same as for the mercurial thermometers; as in these, also, the freezing-point and a temperature of 90° or 95° were determined with reference to short scales on the stems; the distances OF, OH (figure, page 184) were also measured; and by comparing these measurements with the

numbers obtained by calibration, they were expressed in terms of lengths of the calibrating column.

The equation (1.) may be put under the form $N=A(T+\theta T^2)$ by making $\theta=\frac{B}{A}$. Let f and h be the distances OF, OH expressed in steps of the calibrating column; $FH=h-f$. Let T_h be the number of degrees above 32° corresponding to H, and let α_0 be the value, in terms of a calibrating step, of one degree at the temperature 32°: we have then, according to the fundamental equation (1.),

$$h-f=\alpha_0\,(T_h+\theta T_h^2) \text{ or } \alpha_0=\frac{h-f}{T_h+\theta T_h^2}.$$

We may in general, without sensible error, assume that the value of one degree is uniform throughout the length of a single calibrating step, or if the column of mercury has been rather too long, we may subdivide the steps by interpolation. From the value of α_0, now obtained, we can find with sufficient exactness the temperature corresponding to the middle of the step f. It will now be convenient to make use of a table, derived from the values of A and B, showing the relative lengths of one degree at different temperatures on the supposition of uniform capacity of the tubes. The following are the values for every ten degrees, from −70° to +100° Fahr.:—

Temp. Fahr.	λ.	Temp. Fahr.	λ.
−70°	0·831	+20°	0·980
−60	0·848	30	0·997
−50	0·864	40	1·013
−40	0·881	50	1·030
−30	0·897	60	1·046
−20	0·914	70	1·063
−10	0·930	80	1·079
0	0·947	90	1·096
+10	0·964	100	1·112

The value in degrees of the step $f=\frac{1}{\alpha_f}=K_f$. Then calling the numbers in the table λ, since $\frac{\alpha_0}{\alpha_f}=\frac{\lambda_0}{\lambda_f}$, we find $K_f=\frac{1}{\alpha_0}\cdot\frac{\lambda_0}{\lambda_f}=\frac{K_0}{\lambda_f}$. This gives us the temperature corresponding to each end of the step f, and we may then proceed in like manner to find the values of the neighbouring steps, and so obtain successively the values throughout the whole range of the thermometer. The temperature corresponding to the point O in the figure is found by subtracting the sum of all the values of K between O and F from 32°. The length, in turns of the dividing screw, for any degree x is $\frac{R_x}{K_x}$, where R is the length of the step in which x occurs, and K_x the equivalent number of degrees. A table can then be constructed, showing the lengths of each successive degree, commencing from the point O, by the aid of which the graduation may be performed. The scales extend to −75° Fahr.

The time at my disposal was scarcely sufficient to test the thermometers supplied to the Arctic Expedition so completely as I should have wished. The mercurial thermometers were after their graduation compared incidentally at two or three different temperatures, and found to agree generally to 0°·1 Fahr. They were all placed in melting ice, when it was found that four of them read exactly 32°, the other three, viz. Nos. 34, 46, 47, were about 0°·1 too low. In a few of these thermometers the column of mercury could be readily broken: when this column was moved to different portions of the scale, it was found to occupy precisely the same number of divisions. This was the case with four of the instruments; the other three not having been tested in this way.

The five spirit thermometers were compared at four different temperatures with a standard mercurial thermometer. The comparison at 0° being taken in ice and salt, is not very trustworthy. Their errors were as follows:—

Temp. by mer. stand.	S. 2.	S. 4.	S. 6.	S. 7.	S. 8.	Mean of errors.
°	°	°	°	°	°	°
65	+0·8	−0·3	−0·2	+1·3	−0·1	+0·30
52	+0·8	−0·2	−0·3	+1·4	0·0	+0·34
32	+0·8	−0·1	−0·3	+1·4	−0·3	+0·30
0	+0·6	0·0	0·0	+1·7	+0·2	+0·50

The numbers in the column "Mean of errors" seem to indicate little error of a systematic nature. In the case of Nos. 2 and 7, the index error is very large: this, it is believed, is owing to some of the vapour of alcohol having become condensed in the upper portion of the tube before the fixed points were determined, and having escaped my notice; in fact the greatest attention is required to avoid errors from this source. These spirit thermometers cannot by any means be considered as standard, although they are doubtless more trustworthy than most of those usually made. The limited time at my command for the completion of the instruments, prevented the possibility of rectifying any blunders into which I might have fallen, owing to my inexperience in such work, and the intricacy of the problem.

John Welsh.

Kew Observatory, April 21, 1852.

2. The Reply of the President and Council to a Letter addressed to them by the Secretary of State for Foreign Affairs, on the subject of the cooperation of different Nations in Meteorological Observations. Communicated by direction of the President and Council.

Somerset House, 10th May 1852.

Sir,—I have the honour to acknowledge the receipt of your letter of March the 4th, transmitting, by direction of the Earl of Malmesbury, several documents received from foreign governments in reply to a proposal made to them by Her Majesty's Government, for their cooperation in establishing a uniform system of recording meteorological observations, and requesting the opinion of the Pre-